CHAPTER XI

EVALUATION OF THE FEASIBILITY OF USING MULTISPECTRAL DATA TO ASSESS MOISTURE STATUS IN CORN

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ABSTRACT

The reflectance or emittance of electromagnetic radiation from a cropped surface is influenced, among other things, by the moisture status of the crop. The principal objective of the research reported here was to determine whether or not spectral data from any of eleven visible, near infrared or thermal infrared wavebands of a multispectral scanner on a NASA airplane could be used to detect water stress in corn (Zea mays L.). A second objective was to evaluate whether or not hail damage in corn could be detected from the multispectral data.

The hail damaged corn reflected more radiation in the visible and less in the near infrared and thermal infrared portions of the electromagnetic spectrum than did the undamaged corn. The effects of hail damage were still detectable on the imagery several weeks after the damage occurred.

Data from the thermal channel showed differences between the water-stressed and non-stressed corn. Temperature gradients were clearly evident on the thermal imagery of plots with soil water gradients.

The variability of the scanner data on a given plot appeared to be greater than the temperature variability detected from ground based measurements. This was thought to be caused, for the most part, by differences in the viewing angles of the aircraft and based instruments. The scanner aboard the aircraft viewed at an

almost vertical angle. This permitted the detection of radiation emitted from the soil, while the infrared thermometer on the ground viewed the plots at oblique angles so that essentially only vegetation was seen. The use of thermal imagery to detect crop water stress looks promising.

There was a slight, but detectable, increase in reflected visible and near infrared radiation with an increase in water stress of the corn. These changes were so small that they may not be useful for quantifying crop water stress. Certainly, the response of corn to water stress was more easily detected with the thermal data. Additional studies of the effects of water stress on reflected and emitted radiation in the visible, near infrared, middle infrared and thermal infrared portions of the electromagnetic spectrum are recommended.

INTRODUCTION

The reflectance or emittance of electromagnetic radiation from a cropped surface is influenced by several biological and physical factors including crop type, percent crop cover, plant biomass, plant architecture, plant water status, the flux density of impinging radiation, solar elevation, etc. The response of vegetation to incident radiation is a function not only of environmental and plant conditions, but also of the wavelength of the radiation incident upon the plant. Hoffer (1978) summarizes certain of these responses as follows: "Distinct differences are found among the visible, near infrared and middle infrared portions of the spectrum. In the visible wavelengths, the pigmentation of the leaves is the dominating factor. Most of the

incident energy is absorbed and the remainder reflected. The internal structure of the leaves control the level of reflectance in the near infrared where about half of the energy is reflected, nearly half is transmitted and very little is absorbed by the leaf. The total moisture content of the vegetation controls the middle-infrared reflectance, with much of the incident energy being absorbed by the water in the leaf, the remainder being reflected."

Therefore, moisture stress should cause changes in the reflective and emissive characteristics of vegetation and it should be possible to detect moisture stress by remote sensing techniques. This is especially true if instrumentation is available for detecting spectral signatures in relatively narrow and discrete wavebands. Research has demonstrated that the reflectance of vegetation is affected, among other things, by plant water status (Knipling, 1970; Meyers, et al., 1970; Woolley, 1971; Blum et al., 1978; Tucker, Elgin and McMurtrey, 1979).

Other chapters in this report deal almost exclusively with responses of vegetation to water stress as indicated by the radiation emitted in the thermal infrared waveband. There is much yet to be learned about the spectral responses of various kinds of vegetation and the factors which influence spectral response patterns. The primary purpose of this study was to determine whether or not spectral data from any of eleven visible, near infrared (NIR) and thermal infrared wavebands of a multispectral scanner carried aboard a NASA aircraft can be used to detect water stress in corn (Zea mays L.). A second objective was to evaluate the potential of these data for detecting hail damage

to a corn crop.

The instrument aboard the NASA aircraft was used to collect data only in the visible, near infrared and thermal infrared portions of the spectrum. No observations were made of the middle-infrared region. A brief summary of studies which provide insight into expected changes in reflectance due to moisture stress in the visible and NIR regions of the electromagnetic spectrum follows.

Hoffer and Johansen (1969) showed that changes in the reflectance of individual corn leaves did not occur in either the visible or NIR regions until the moisture content of the leaves had fallen below 66%. After this point, there was a steady increase in reflectance in both the visible and NIR as leaf moisture content declined. Sinclair (1971) found a detectable increase in reflectance in the NIR from sorghum leaves as they decreased from 76% to 73% water content.

These laboratory studies indicate that reflectance in the visible and NIR spectrum can be expected to increase as water stress increases in severity. The magnitude of these increases should be relatively small, but detectable.

The results from field studies are not so clear. Tucker (1979, 1980) reported that reflectance in the 0.63-0.69 μm range (visible red) increased with decreasing leaf water content in corn and soybean canopies. Reflectance in the 0.75-0.8 μm (NIR) range, however, decreased with decreasing leaf water content.

Decreases in NIR reflectance due to moisture stress in the field appear to contradict the findings of laboratory measurements. This apparent contradiction may be explained, however.

Meyers et al. (1970) showed that NIR reflectance from cotton leaves was strongly dependent on the number of leaf layers. NIR reflectance decreased by nearly 50% as the number of leaf layers was reduced from 6 to 1. The reason for the decreased reflectance with decreased numbers of leaf layers is illustrated in a diagram from Hoffer (1978)(Fig. 1). In his model leaves reflected 50% and transmitted 50% of the incident NIR radiation. An increase in moisture stress should cause an increase in NIR reflectance of individual leaves. If moisture stress results in loss of leaves, however, NIR reflectance from a canopy would decrease. It is, therefore, conceivable that NIR reflectance measurements in field crops may increase, decrease, or show no change because of moisture stress.

MATERIALS AND METHODS

Experiment Site

This experiment was conducted in 1979 in the solid set irrigation area at the University of Nebraska Sandhills Agricultural Laboratory (SAL), located near Tryon, Nebraska (41° 37' N; 100° 50' W; 975 m above mean sea level). Interpretation of the multispectral data obtained at SAL requires an understanding of the general nature of several experiments conducted concurrently (Fig. 2).

The north-eastern portion (A-area) was devoted to a large-scale moisture stress experiment on corn. The plots in A-area were subjected to varying degrees of stress throughout the growing season. Details of irrigation and plant population treatments on several of these plots are given in Fig. 1 of Chapter VIII.

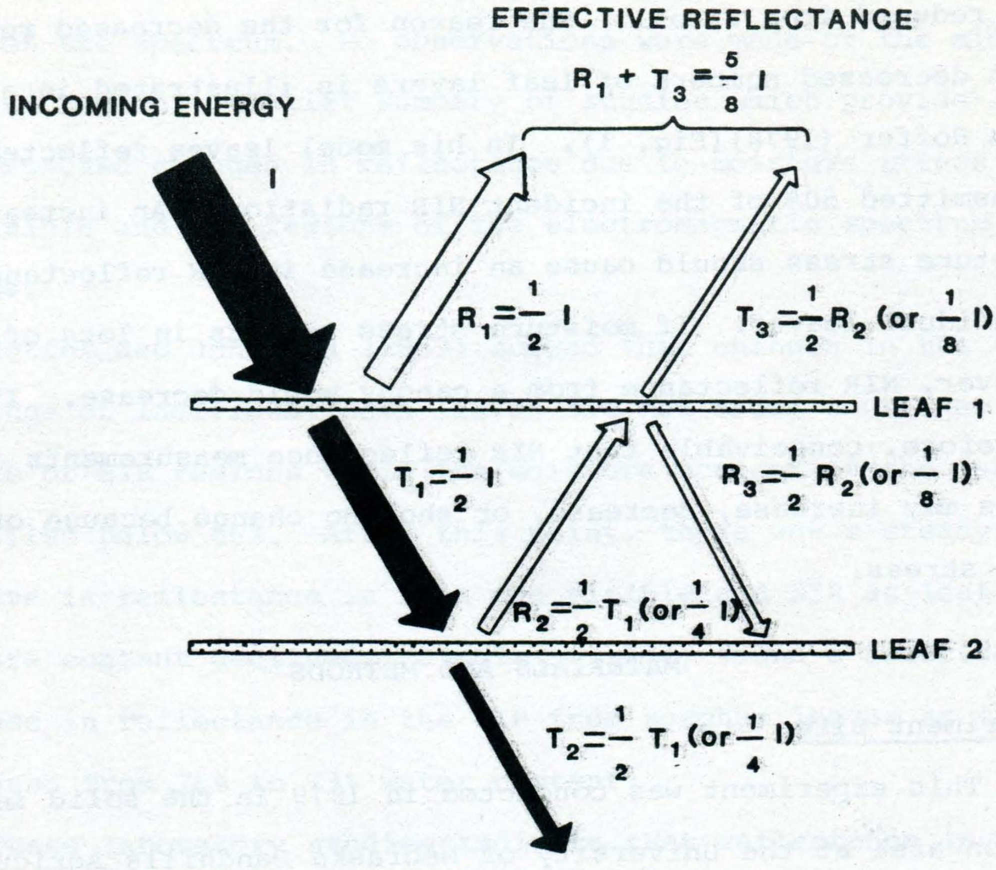


Fig. 1. Simplified sketch of the effect of multiple-leaf layers on vegetative reflectance. I = incoming energy; T = transmitted energy; R = reflected energy (from Hoffer, 1978).

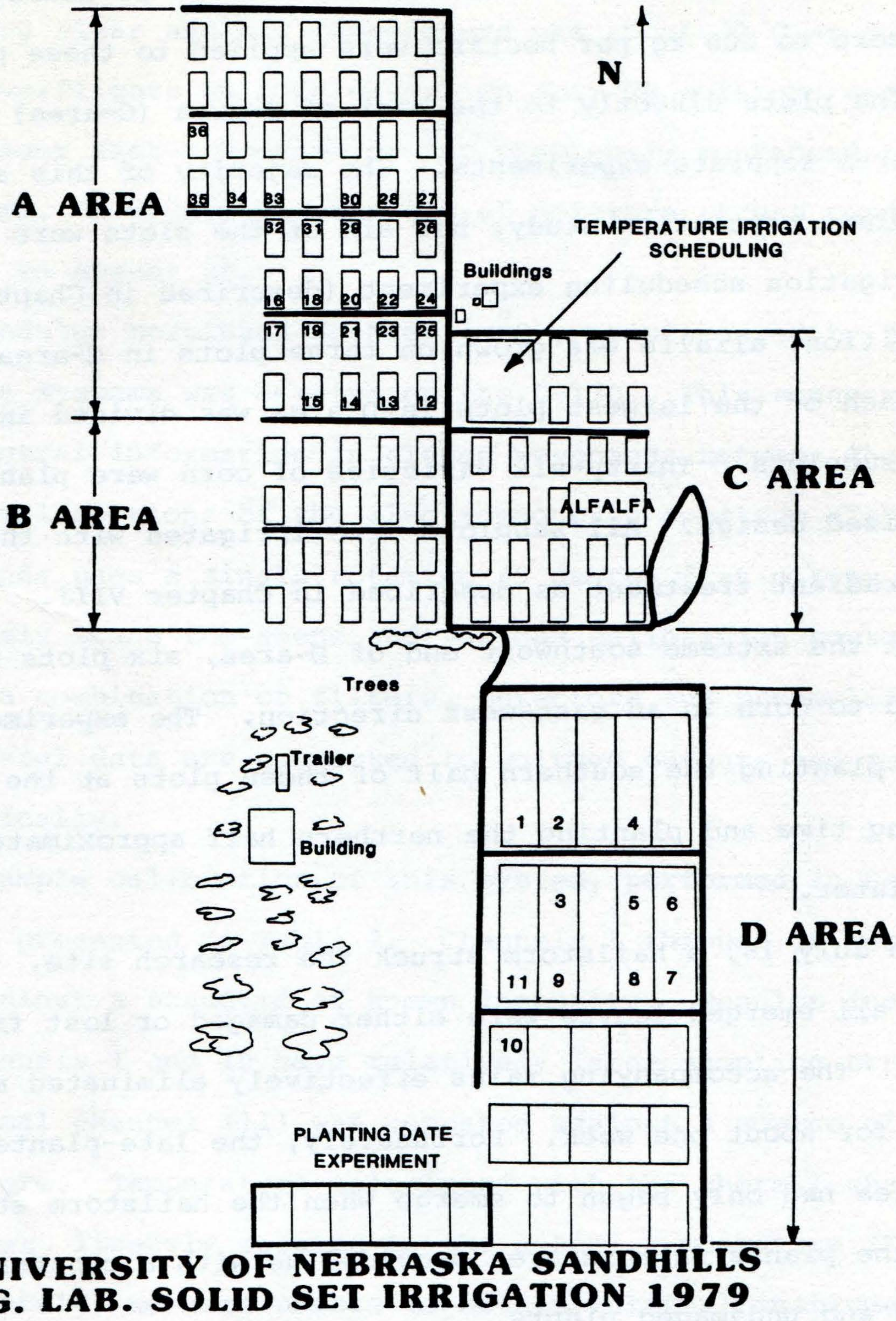


Fig. 2. Location of all plots in the solid set area at the Sandhills Agricultural Laboratory. Numbered plots were used in crop temperature studies.

B-area, directly to the south of A-area, was devoted primarily to a nitrogen application experiment. Levels of nitrogen ranging from zero to 200 kg per hectare were applied to these plots.

The plots directly to the east of B-area (C-area) were used for three separate experiments. The majority of this area was part of a plant population study, but six of the plots were devoted to an irrigation scheduling experiment (described in Chapter VII). In addition, alfalfa was grown on three plots in C-area.

Each of the largest plots in D area was divided into seven small subplots. Thirty-six varieties of corn were planted in a randomized design. All subplots were irrigated with the GIG moisture gradient treatment as described in Chapter VIII.

At the extreme southwest end of D-area, six plots were planted to corn in an east-west direction. The experiment involved planting the southern half of these plots at the normal planting time and planting the northern half approximately one month later.

On July 16, a hailstorm struck the research site. Virtually all emerged leaves were either damaged or lost from the plants. The accompanying rains effectively eliminated moisture stress for about one week. Fortunately, the late-planted corn in D-area had only begun to emerge when the hailstorm struck. Thus, the plants in this area provided us with a constrast between damaged and undamaged plants.

Multispectral Data

An instrumented C-130 aircraft from the NASA headquarters at the Johnson Space Center in Houston, Texas, flew at an altitude

of 500 m over the experiment site twice in 1979. Data were collected at 1100-1130 hrs (solar time) on July 20 and August 30. Skies were clear and air temperature was about 30 C at the time of the overflights on both days. On July 20 moisture stress was only a minor factor because of the previously mentioned hail and rain storm. A widely ranging set of moisture stress conditions occurred on August 30.

A Modular Multiband Scanner (M^2S), manufactured by Bendix Aerospace Systems was carried on the C-130. This scanner collects multispectral information in eleven wavebands between the visible and thermal portions of the electromagnetic spectrum (Table 1). The scanner uses a single rotating 45 degree flat mirror which alternately scans the scene and various calibration sources. Through a combination of filters, detectors and preamplifiers, the spectral data are converted to voltage outputs and recorded electronically.

A sample calibration of this system, performed in December, 1975, is presented in Table 2. Channels 1 through 10 were compared against a standard of known intensity. Results indicate that channels 1 and 10 have relatively large sampling errors. The thermal channel (11) was compared against a source of known temperature. Temperature calculated with the thermal channel output was linearly related to the actual temperature (Fig. 3). Unfortunately, we were unable to obtain internal instrument temperature calibration data during the time of the flight. Thus, we cannot directly assign temperature values directly to the data from channel 11.

Table 1. The eleven channels used in the Bendix Modular Multiband Scanner.

Channel	Waveband Interval (μm)
1	0.42 to 0.46
2	0.46 to 0.50
3	0.50 to 0.54
4	0.54 to 0.58
5	0.58 to 0.62
6	0.62 to 0.66
7	0.66 to 0.70
8	0.70 to 0.74
9	0.77 to 0.86
10	0.96 to 1.04
11	7.89 to 11.60

Table 2. Sample calibration of the Bendix Modular Multiband Scanner, December 3, 1975, comparing the average and standard deviation of 100 consecutive scan lines of a laboratory standard.

Channel	Signal Average	Signal Standard Deviation
1	89.42	7.2095
2	83.44	1.4335
3	71.112	0.86052
4	66.367	0.67986
5	70.459	0.60481
6	82.29	0.73195
7	101.38	0.75585
8	138.61	0.74914
9	163.86	1.0248
10	134.20	5.3295

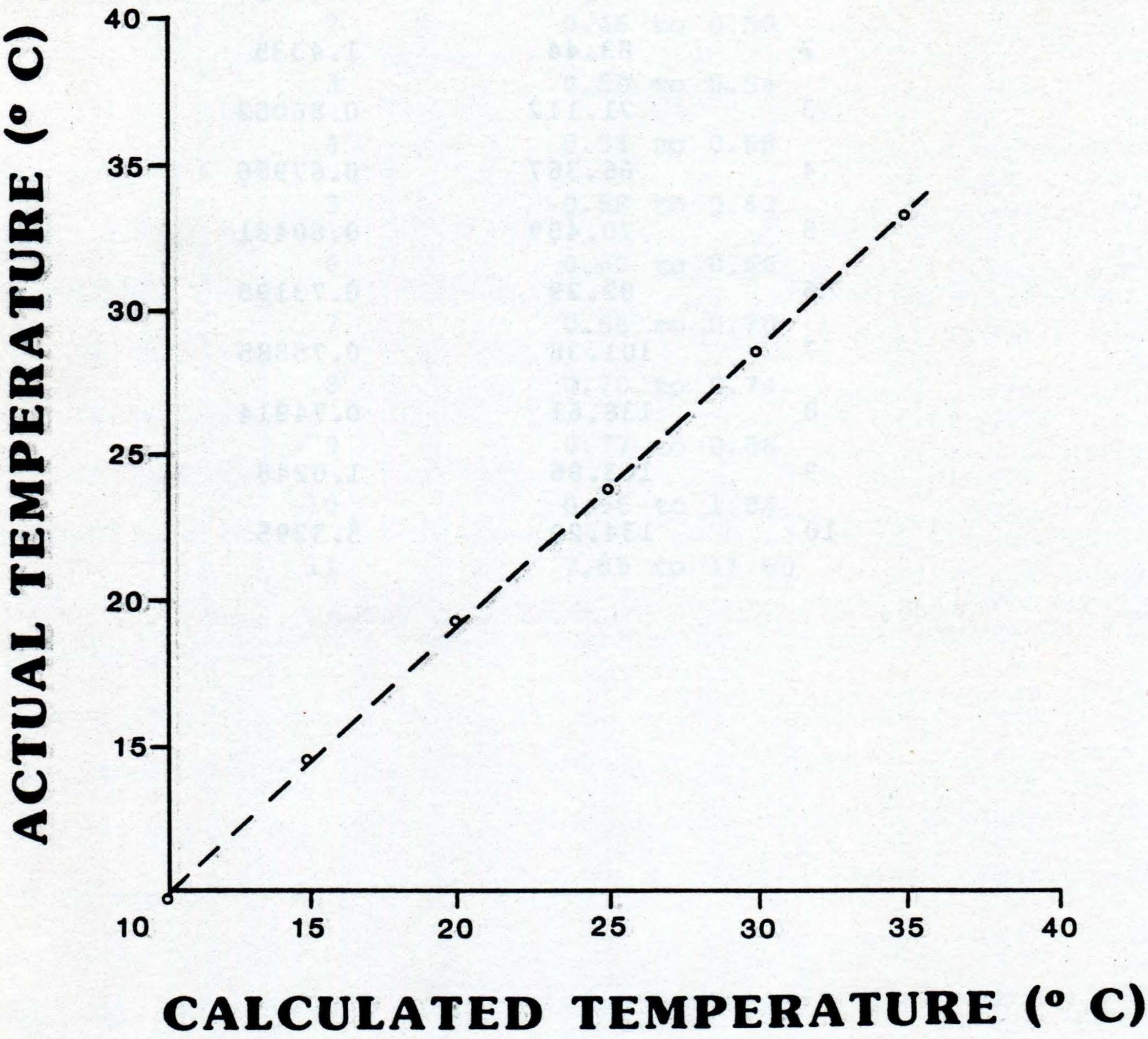


Fig. 3. Comparison of the actual temperature and the temperature calculated with signals from the thermal channel (channel 11) on the M^2S carried on the NASA airplane.

Ground Based Data

During the times of the NASA overflights, observers on the ground made observations of crop temperature with a Telatemp Model AG-42 Infrared Thermometer (IRT) at sample sites in A-, C- and D-areas.

Statistical Analysis of Data

The computation of means and variances for reflected radiation was performed on a pixel by pixel basis for each channel of data. A pixel was approximately one meter square in size. At least 300 pixels were used to compute each statistic. With so many samples, relatively small differences in reflectance values due to various treatments can be shown to be statistically significant.

RESULTS AND DISCUSSION

Data from channels 4, 6 and 10 were used to make a composite image of the experimental area on both overflight dates (Fig. 4). One of the characteristics of the spectral imagery from A-area is an alternating striped effect. This effect is caused by nitrogen treatments in this area. Nitrogen fertilizer was applied only to the treatment plots. None was applied to the areas between the plots. The between plot areas were nitrogen deficient so that the corn was yellowed and stunted in growth.

On July 20, the contrast between corn (labeled E) and bare soil (labeled L) on the east-west plots at the south end of D-area as seen from a photographic enlargement of this area (Fig. 5) is unmistakable. By August 30, both area L and area E had

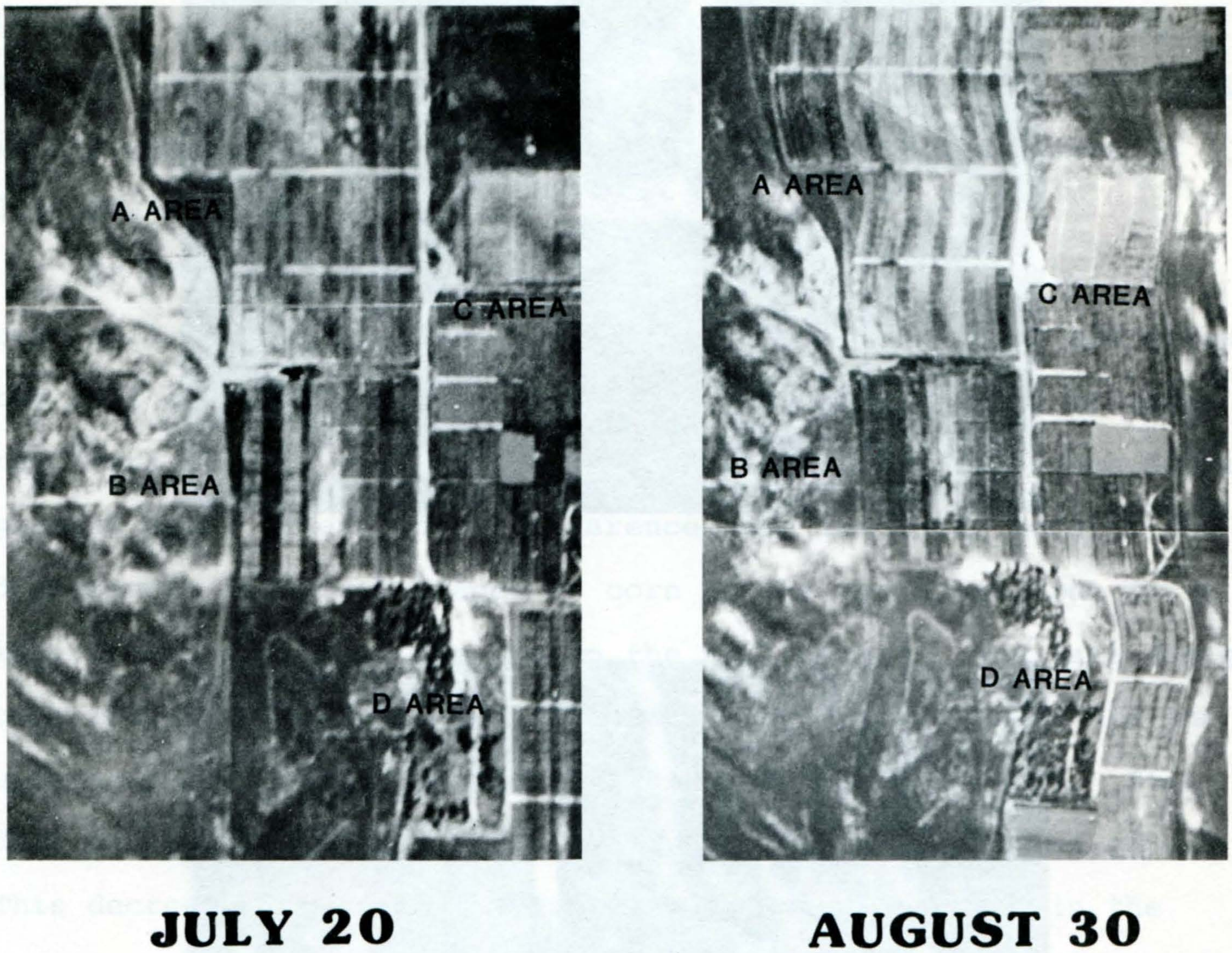


Fig. 4. Three band color composite of the Sandhills Agricultural Laboratory on July 20 and August 30, 1979. Color assignments were: Blue - Channel 4; Green - Channel 6; Red - Channel 10. Due to the high cost of reproducing color photographs, the ones shown here are reproduced only in black and white. North is to the top of the page.

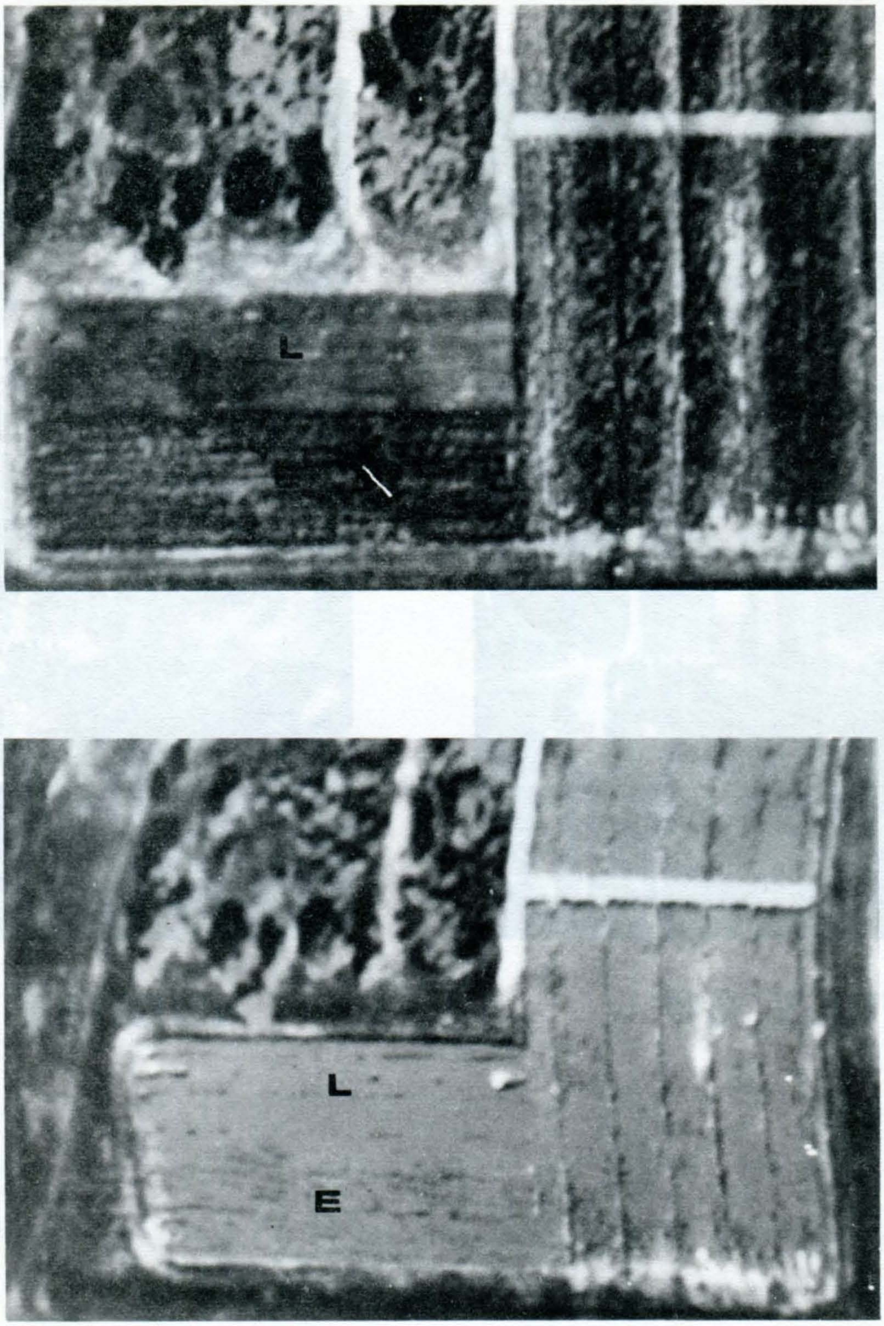


Fig. 5. Enlarged color composite of the south end of D area, showing the contrast between bare soil and a corn crop on July 20 (A) and August 30, (B) 1979. Color assignments were the same as in Fig. 4. Area L is late planted corn and area E is early planted corn.

complete vegetative cover. There was still a distinct difference between the radiation reflected from these two areas.

The patterns observed on these two dates are explained as follows. Except for channels 9 and 10 the light-colored sandy soil at SAL produced higher flux densities of reflected radiation in all channels than did the corn which covered the surface on July 20, 1979 (Table 3).

By August 30, the situation had changed considerably. The bare soil area was now completely covered by corn which had escaped the hail damage. This late-planted area showed up as a brighter red (more uniform gray) on the color composite than did the earlier-planted area. These color differences may indicate, merely, the differences in growth stages of corn in the two areas, but it is more likely that they are due to the hail damage. The hail damaged corn reflected 5-12% more radiation in channels 1-7 than did the undamaged corn and 5-15% less in channels 8-11 (Table 4). Standard deviation was also consistently lower in the damaged corn. This decrease in variability may be due to an increase in the spectral roughness of the hail damaged plot. A spectrally rough surface acts as a diffuser of incoming radiation which, in turn, reduces the variability in reflectance measurements. These results suggest that multi-spectral imagery in the visible and NIR waveband should be useful in delineating areas subjected to hail damage even though several weeks may have elapsed between the time at which the damage occurred and the time when the imagery was obtained.

The effect of hail damage on the thermal radiation sensed by the airborne scanner is shown in the histograms given in

Table 3. Comparison of the relative energy measured in the 11 MS channels from bare soil and corn on July 20, 1979.

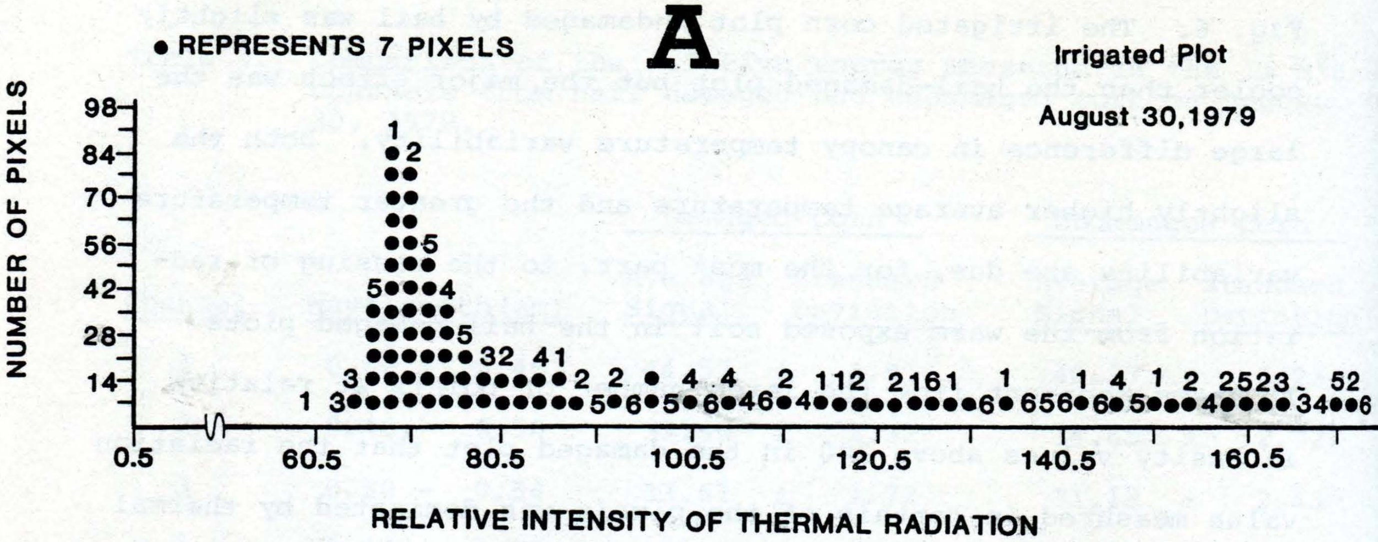
		Bare Soil		Corn	
Channel	Wavelength (μm)	Average Signal	Standard Deviation	Average Signal	Standard Deviation
1	0.42 - 0.46	70.76	± 7.91	48.72	± 4.99
2	0.46 - 0.50	58.42	± 6.17	39.74	± 3.09
3	0.50 - 0.54	43.45	± 3.74	32.36	± 2.09
4	0.54 - 0.58	41.38	± 3.00	32.88	± 2.02
5	0.58 - 0.62	37.53	± 3.30	27.94	± 1.79
6	0.62 - 0.66	36.54	± 4.03	24.65	± 1.98
7	0.66 - 0.70	40.83	± 4.74	26.68	± 2.31
8	0.70 - 0.74	64.39	± 3.77	60.97	± 3.93
9	0.77 - 0.86	89.97	± 9.66	120.91	± 11.34
10	0.96 - 1.04	121.10	± 9.14	143.27	± 11.06
11	7.89 - 11.60	87.86	± 5.84	75.18	± 5.67

Table 4. Comparison of the relative energy measured in the 11 M^2S channels from hail damaged and undamaged corn on August 30, 1979.

Channel	Wavelength (μm)	Damaged Corn Average Signal		Damaged Corn Standard Deviation	Undamaged Corn Average Signal		Undamaged Corn Standard Deviation
1	0.42 - 0.46	44.57	±	4.91	40.27	±	5.23
2	0.46 - 0.50	39.40	±	2.32	34.65	±	2.72
3	0.50 - 0.54	33.61	±	1.72	31.15	±	2.43
4	0.54 - 0.58	31.81	±	1.61	30.46	±	2.90
5	0.58 - 0.62	27.84	±	1.41	25.42	±	2.10
6	0.62 - 0.66	27.97	±	1.43	24.77	±	1.79
7	0.66 - 0.70	28.54	±	1.59	24.94	±	1.93
8	0.70 - 0.74	60.17	±	3.57	63.58	±	6.83
9	0.77 - 0.86	145.49	±	10.27	170.81	±	20.47
10	0.96 - 1.04	165.99	±	10.68	184.18	±	20.15
11	7.89 - 11.60	71.85	±	7.14	75.07	±	8.27

Fig. 6. The irrigated corn plot undamaged by hail was slightly cooler than the hail-damaged plot but the major effect was the large difference in canopy temperature variability. Both the slightly higher average temperature and the greater temperature variability are due, for the most part, to the sensing of radiation from the warm exposed soil in the hail damaged plots. It seems apparent from the large number of points at relative intensity values above 100 in the damaged plot that the radiation value measured in certain of the pixels was dominated by thermal radiation from the soil surface.

Thermal imagery of plots used in the irrigation scheduling experiment (C-area) is given in Fig. 7 for both dates of overflight. On July 20, 1979, little temperature difference was noted between any of the plots although a greater proportion of darker (cooler) areas are apparent in the fully irrigated plot (4) than in the dryland plot (5). Histograms show that values of the relative intensity of thermal radiation were greater for the dryland plot than for the irrigated plot (Fig. 8). This suggests that the dryland plots were slightly warmer. Unfortunately, actual average scanner temperature differences could not be calculated for comparison with the average ground temperatures of 26.2 C in plot 4 and 26.3 C in plot 5. That the ground based temperature differences are small is not surprising since they were made in areas of these two plots showing essentially identical shades of gray (Fig. 7). There appears to be more temperature variability on July 20 in the irrigated plot (4) than in the dryland plot (5). Since it had rained on July 16, we did not expect to observe large temperature differences or a great temperature



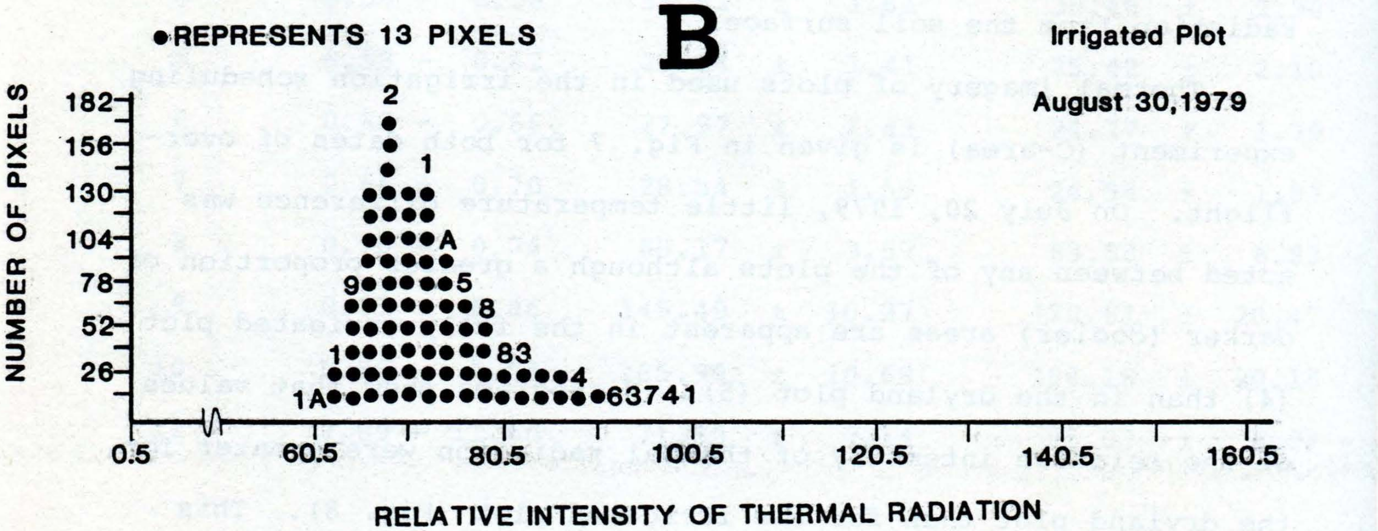


Fig. 6. Histograms of data from channel 11 (7.9-11.6μm) on August 30, 1979, at about 1115 hrs. solar time. A. Data from the hail-damaged plot (E). B. Data from undamaged plot (L). Both plots were fully-irrigated.

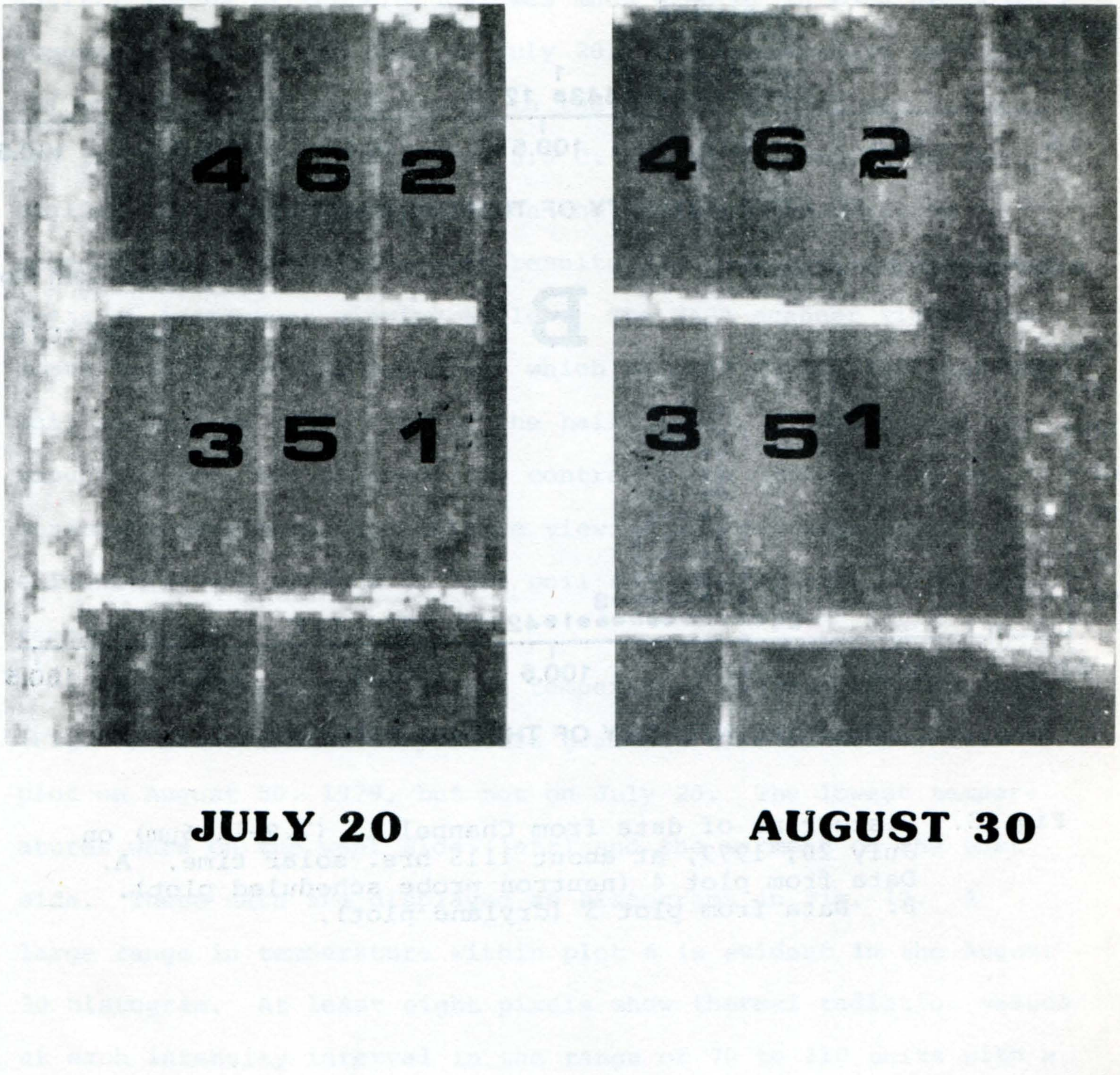


Fig. 7. Thermal imagery (channel 11) for the Irrigation Scheduling plots (C area) on July 20 and August 30, 1979. The light colored lines running E-W are roadways between plots. Those running N-S are sprinkler lines between plots. Areas 1, 2, 3, 4, 5 refer to plots receiving different irrigation treatments (Chapter VII). The darker the color, the cooler the temperature.

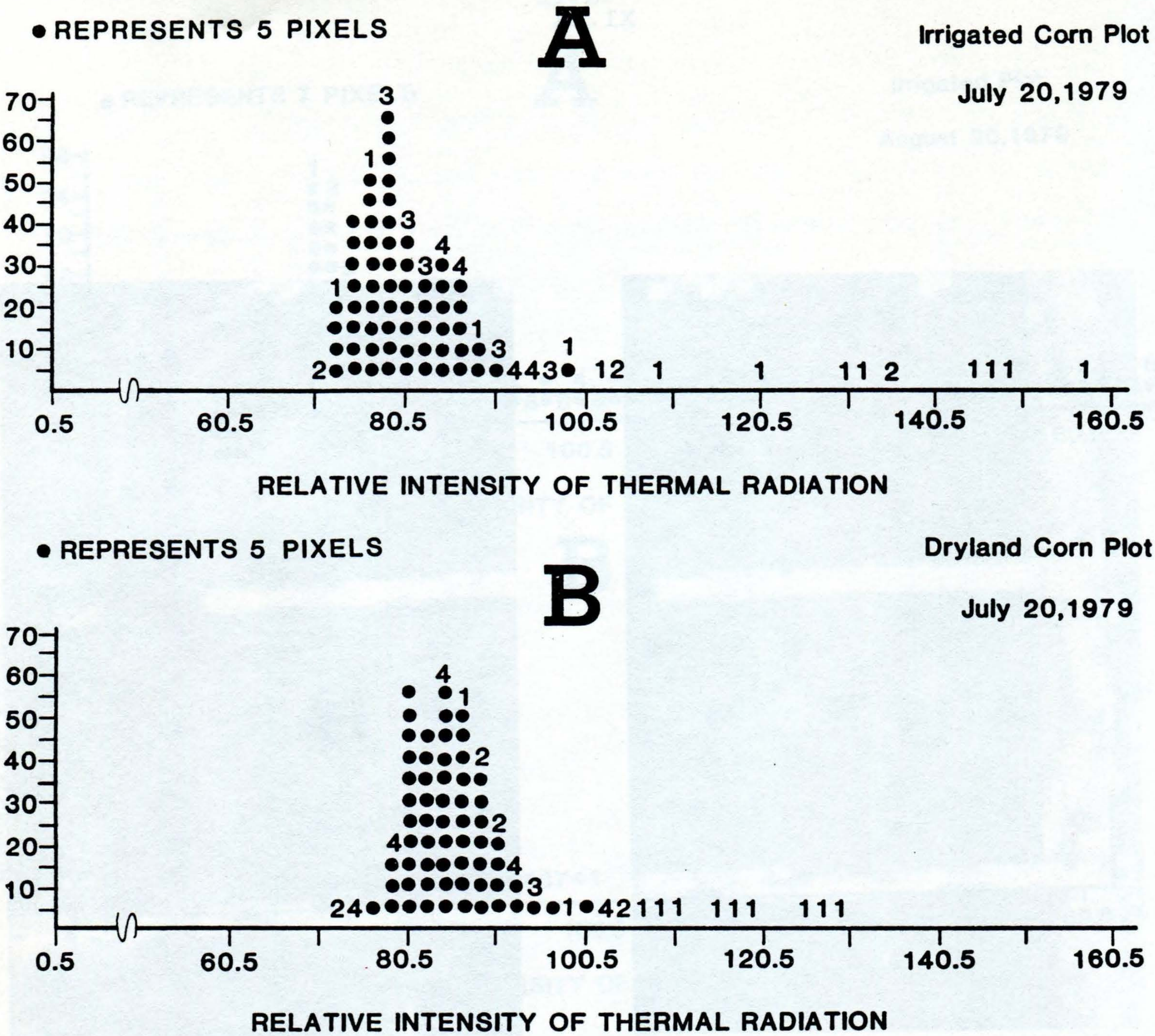


Fig. 8. Histograms of data from Channel 11 (7.9-11.6μm) on July 20, 1979, at about 1115 hrs. solar time. A. Data from plot 4 (neutron probe scheduled plot). B. Data from plot 5 (dryland plot).

variability within any of the plots by July 20.

On August 30, 1979, the thermal imagery (Fig. 7) and the histograms (Fig. 9) show that the irrigated plot was definitely cooler (darker) than the dryland plot. The temperature variability (range of temperature) was much greater in both plots on August 30 than it had been on July 20. The temperature variability of the ground measurements in the irrigated plot was 0.7 C and in the dryland plot it was 0.5 C. These variabilities are smaller than would be expected on the basis of the airborne scanner data. These divergent results are best explained on the basis of instrument viewing angles. The NASA scanner viewed the plots from a vertical position, which allowed it to view exposed soil as well as crop. Due to the hail damage, a substantial amount of soil was exposed. By contrast, the ground based measurements were made from oblique viewing angles, essentially eliminating any effects of bare soil on observed crop canopy temperatures.

Careful examination of the temperature pattern in plot 6 (Fig. 7) shows that a temperature gradient existed across this plot on August 30, 1979, but not on July 20. The lowest temperatures were on the west side (left) and the warmest on the east side. These data are displayed as histograms in Fig. 10. A large range in temperature within plot 6 is evident in the August 30 histogram. At least eight pixels show thermal radiation values at each intensity interval in the range of 70 to 110 units with a number of pixels in the range up to 170 units. This rather broad range of values is due, not only to the differences in plant temperatures caused by the various levels of water stress, but also

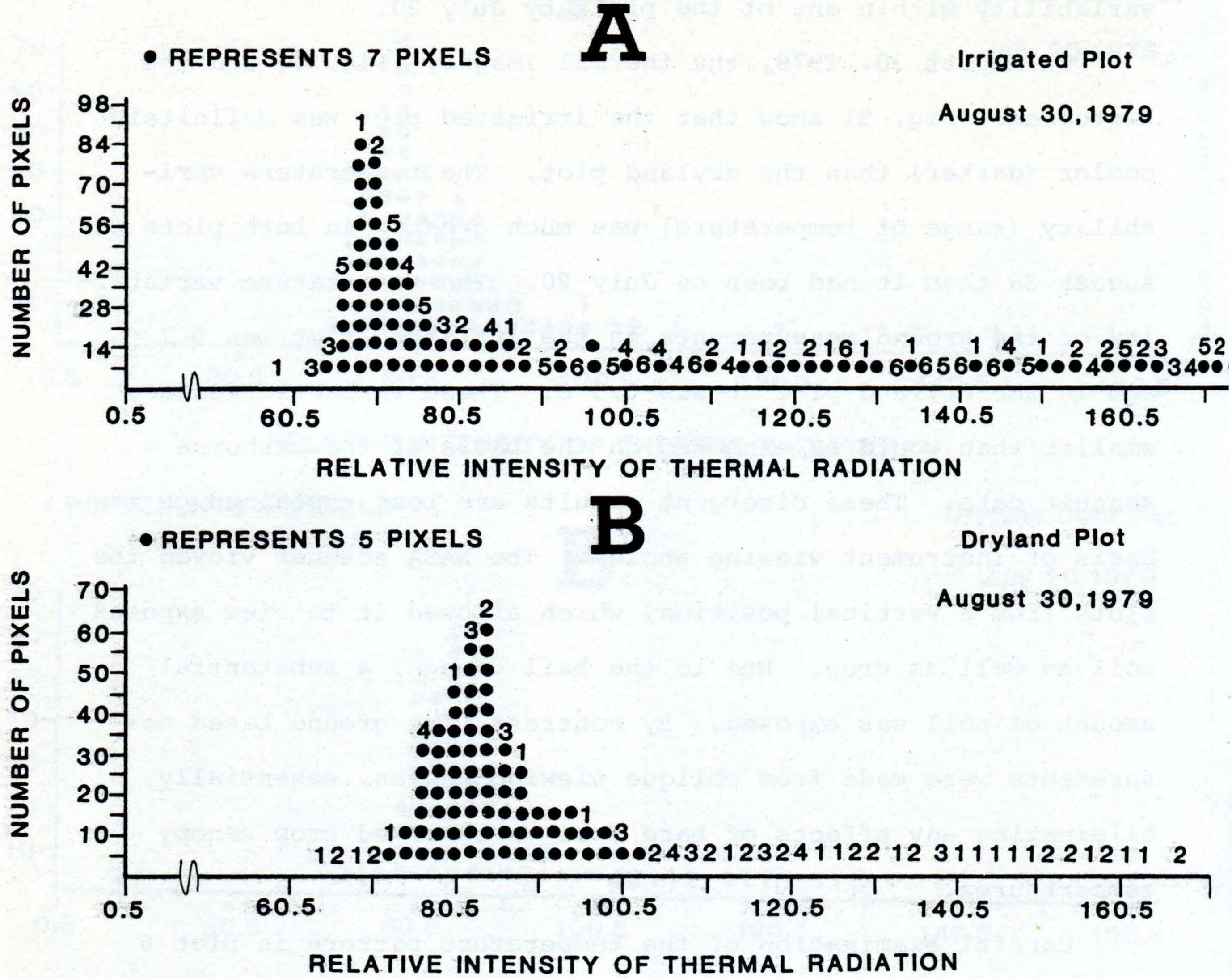


Fig. 9. As in Fig. 8 for August 30, 1979.

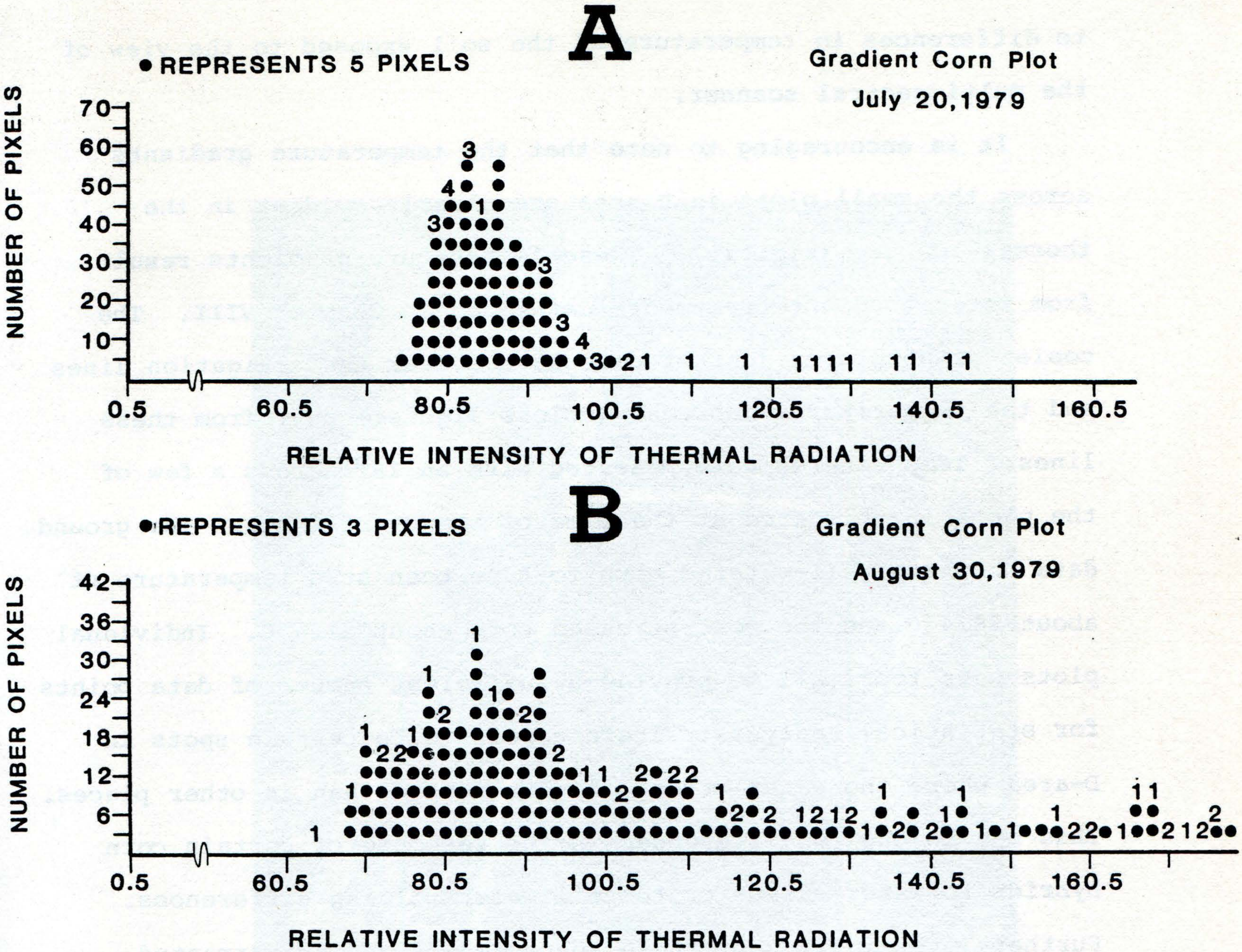


Fig. 10. Histograms of data from Channel 11 (7.9-11.6μm) on July 20 (A) and August 30, (B) 1979 at about 1115 hrs. solar time from plot 6 (gradient plot).

to differences in temperature of the soil exposed to the view of the multispectral scanner.

It is encouraging to note that the temperature gradients across the small plots in D area are clearly evident in the thermal imagery (Fig. 11). These temperature gradients result from water gradient treatments described in Chapter VIII. The cooler temperatures (darker colors) are near the irrigation lines and the temperatures increase (colors lighter) away from these lines. Temperatures were measured with an IRT across a few of the plots in this area at the time of the overflights. The ground data show the well-watered corn to have been at a temperature of about 28.4 C and the most stressed corn about 31.6 C. Individual plots were too small to provide a sufficient number of data points for statistical analysis. There appear to be certain spots in D-area where the water stress is more severe than in other places. This may be due to differences in the response of certain corn hybrids to water stress or to soil water holding differences. Further investigation of these suspected causes is warranted.

The overflights were made 2 to 3 hours before the time of day when maximum crop canopy temperature differences due to water stress are expected. Thus, the observed temperature differential between well-watered and stressed vegetation was smaller during the time of the overflight than if they had been made around 1400 hrs. Nevertheless, temperature differences at 1115 hrs were readily detected in the thermal imagery - a promising finding. Further studies are needed to evaluate and quantify crop temperatures-plant water status relationship and to further elucidate the relationships between crop canopy temperatures measured at

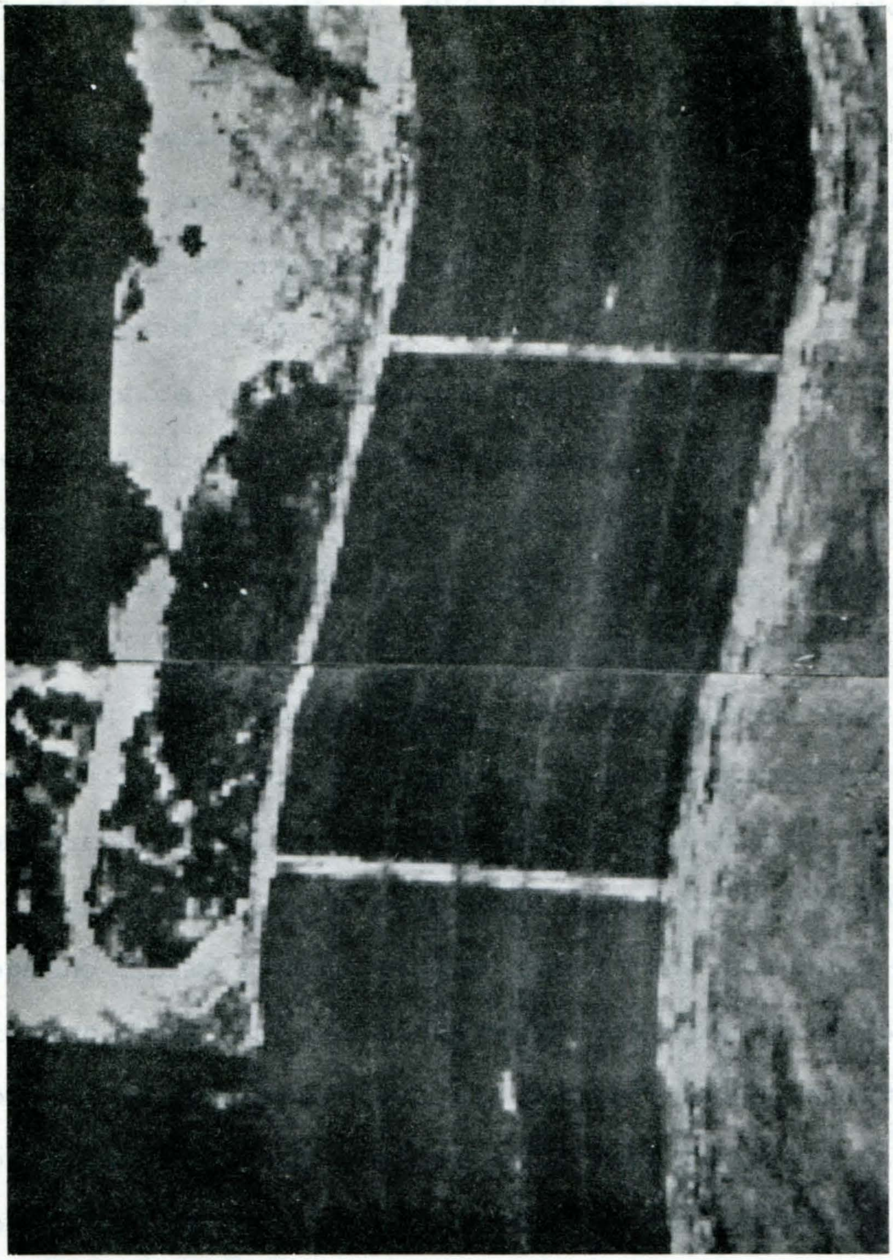


Fig. 11. Thermal imagery (Channel 11) of the water gradient treatments in area D on August 30, 1979. The two thin lines running N-S to the right and left of the center of the field are the irrigation sprinkler lines. The water gradients are applied on either side of these lines.

the surface and those made from airborne platforms.

In order to evaluate whether or not visible and NIR radiation might also aid in the detection of plant water stress, data are plotted for August 30, 1979, in Figs. 12 and 13 for channels 1-10 for each of the five plots used in the irrigation scheduling experiment. A slight increase in the average reflectance value in each of the channels with increasing crop water stress is apparent in these figures. The differences are probably too small, however, to be useful in quantifying water stress in corn.

The very different reflectance values obtained in the 3 SMW plot (plot 2) can be explained as follows. A third or half of plot 2 lies in a problem area. The exact nature of the problem is not yet known but the area does show up clearly on imagery from all channels on August 30. (See Fig. 14 for an example of the imagery obtained.) It is undoubtedly this problem area which causes the large changes in crop reflectance values and which results in the rather large differences in standard deviation values observed for data from several of the channels.

We conclude that water stress causes small changes in the reflectance of corn in the visible and NIR portions of the spectrum. Since these changes are small, we feel that crop water stress is detected much more readily from thermal imagery. We do feel, however, that further studies of the influence of water stress on reflection of radiation from cropped surfaces are warranted. These studies should involve selected wavebands in the visible, NIR, middle infrared, and the thermal infrared regions of the spectrum.

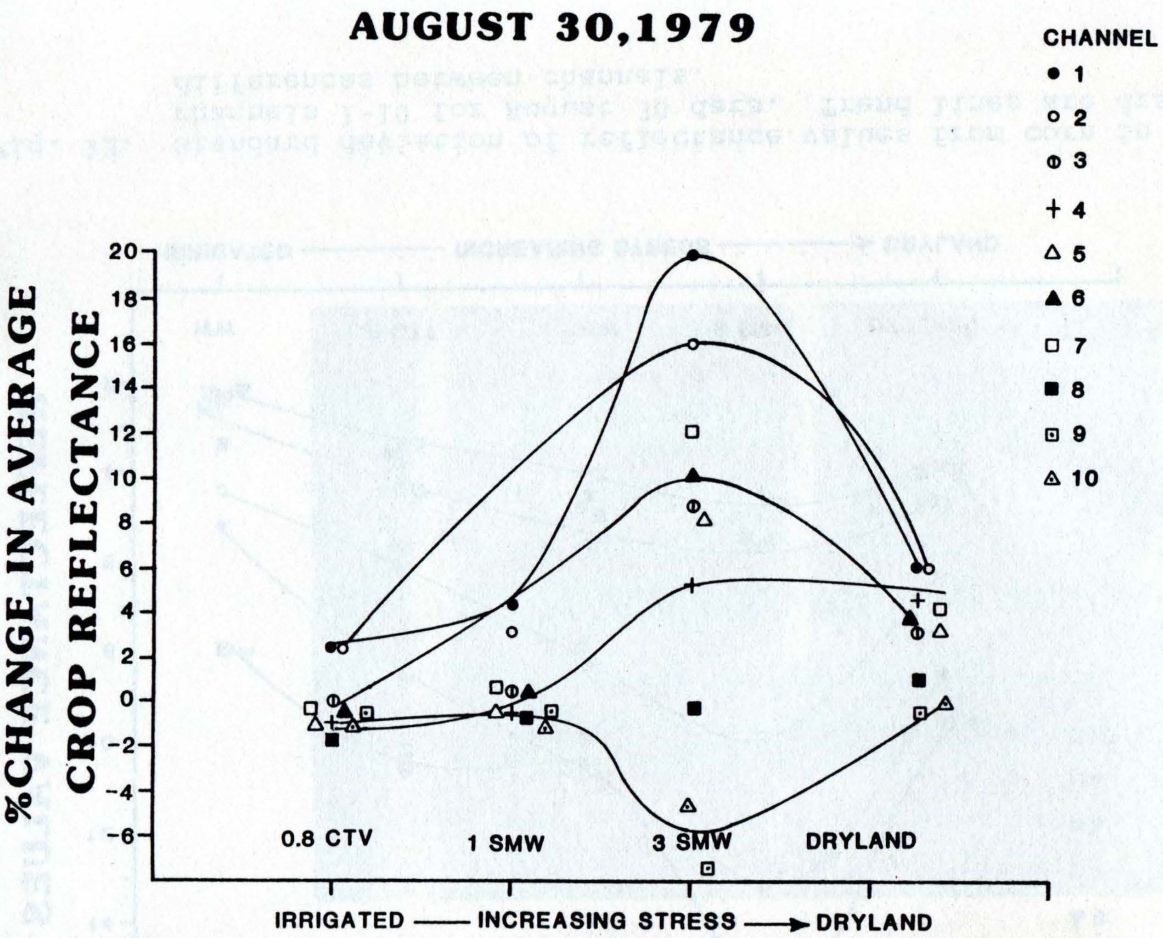


Fig. 12. Increasing stress change in average corn reflectance in channels 1-10, as a percent of the reflectance from irrigated plots on August 30, 1979. Trend lines are drawn to clarify differences between channels.

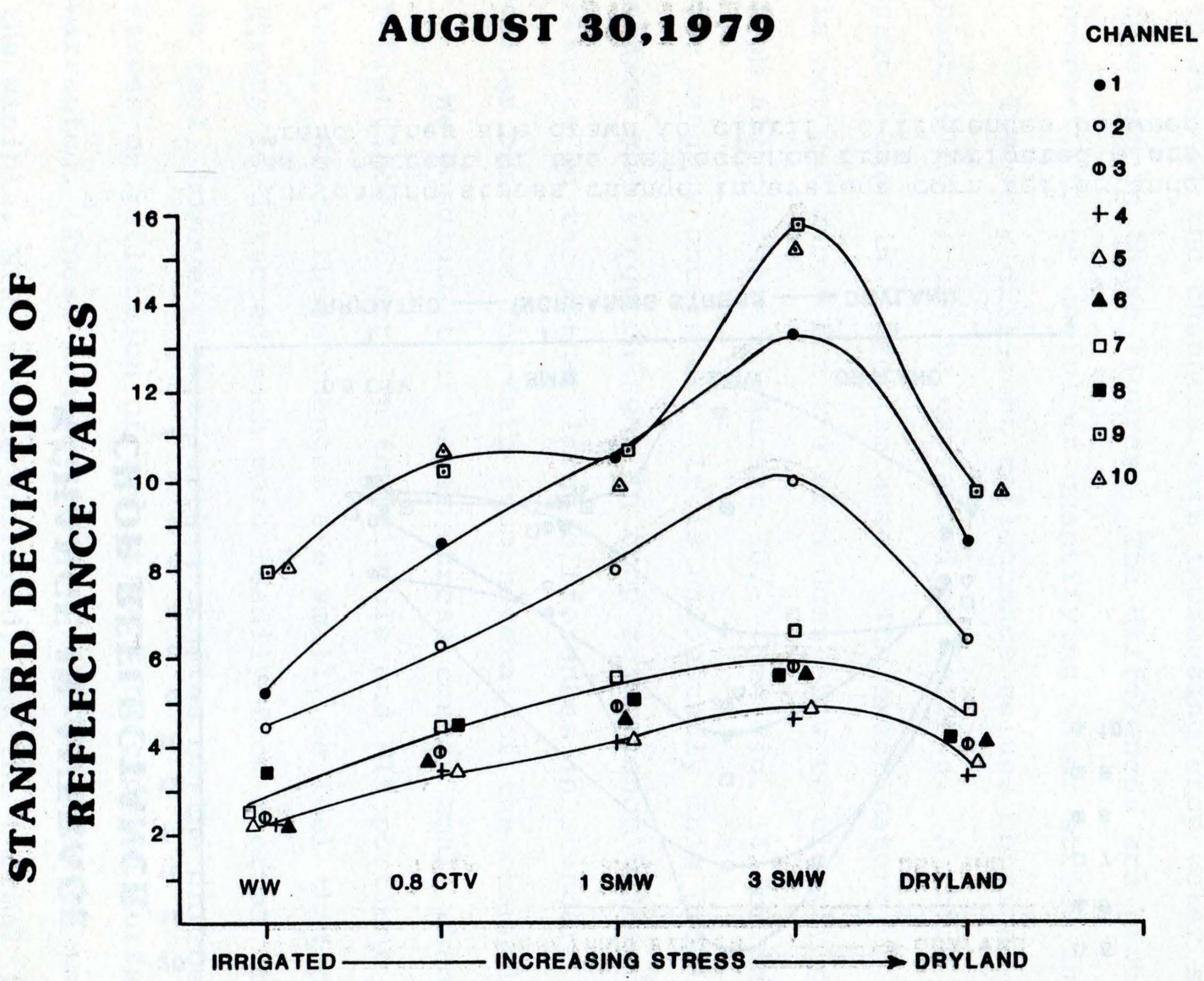


Fig. 13. Standard deviation of reflectance values from corn in C area in channels 1-10 for August 30 data. Trend lines are drawn to clarify differences between channels.

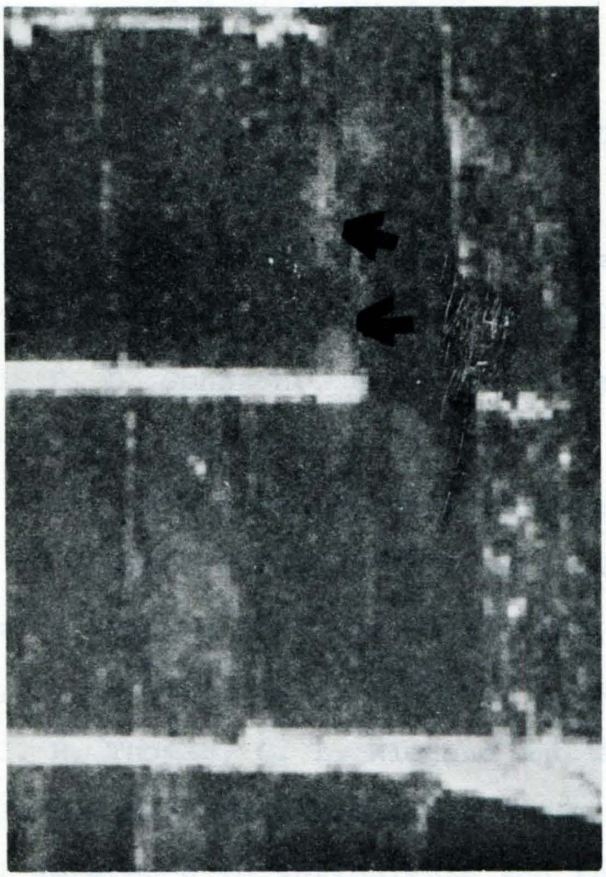


Fig. 14. Imagery from the temperature irrigation scheduled plots in C area. Data are from Channel 6 (0.62-0.66μm range) on August 30, 1979. The arrows show the problem area in the 3SMW plot (plot 2).

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